

LETTER

An Efficient Optical Burst Switching Technique for Multi-Hop Networks**

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SUMMARY In this letter, we investigate the path length priority effect of existing just-enough-time (JET) scheme for optical burst switching (OBS) in the multiple hop network environments. And, we propose a novel hop-by-hop priority increasing (HPI) scheme using the input fiber delay lines (FDLs) at each node. Simulation results showed that the proposed FDL/delayed reservation (DR) with HPI scheme can avoid the path length priority effect and enhance the end-to-end throughput in multiple hop network environments.

key words: optical burst switching, wavelength reservation

1. Introduction

The rapid growth of the Internet has resulted in an increasing demand for transmission capacity in core backbones. As the growth of these demands out paces the capabilities of electronic switches and traditional transmission techniques, core networks must evolve to new architectures based upon all optical switching and dense wavelength division multiplexing (DWDM) technologies. Optical burst switching (OBS) has been proposed as the technology basis for such an all-optical Internet [1]–[3]. OBS combines the benefits of optical circuit switching and optical packet switching and, as such, it maintains the efficiency of optical packet switching while reducing the implementation complexities.

In OBS, the bandwidth for a data burst is generally reserved in a one-way process. That is, the source sends the control packet on a separate channel in order to reserve the bandwidth of the data channel, and then transmits data burst without waiting a confirmation for a successful reservation. Since control packets are converted to the electronic domain for processing and there are delays involved in setting up the optical switching matrix in each core node, one must carefully coordinate the timing of control and data planes. Generally, the compensation for the processing time of the control packets can be implemented using an offset time (OT) based scheme or a fiber delay line (FDL) based scheme [1]–[2].

The OT-based scheme computes an offset time T at the

source node for each control packet based upon the estimated sum of the processing times for the control packet plus the switch setup times at each core node on the path [1]. That is, the transmission of data burst is delayed at the source node by the basic offset time T after transmitting its control packet. Because the burst is buffered at the source in the electronic domain, no FDLs are necessary at each intermediate node to delay the burst while the control packet is being processed. Meanwhile, in the FDL-based scheme, data burst can be immediately transmitted after transmitting control packet and the processing time of the control packet plus the switch setup time is compensated by delaying the data burst at each core node using an input FDL [2].

Typically, the FDL-based scheme is more complex to implement because it requires input FDLs at core node. However, the OT-based scheme has other complexities in their operation. In the OT-based scheme, the source node must know the complete path routing information of a data burst in order to calculate the basic offset time. Moreover, protection and restoration algorithms must more carefully select a backup path so that the number of hops for the backup path does not exceed that of primary path. The Table 1 compares the characteristics of the OT-based scheme and the FDL-based scheme.

Wavelength reservation schemes in OBS core nodes can be classified as either immediate reservation (IR) [3] or delayed reservation (DR) [1] schemes. In an IR scheme, wavelength reservation starts immediately after processing of the control packet finishes. In a DR scheme, the wavelength for a data burst is reserved starting from the time at which the burst is expected to arrive. An IR scheme can be implemented with low complexity. However, a DR scheme can improve efficiency by reserving a channel only during actual burst transmission time. Moreover, a DR scheme can support multiple classes of service by using an extra QoS offset time [4].

Recently, various wavelength reservation schemes for OBS have been proposed, including the just-enough-time (JET) [1], the terabit burst switching mechanism [2], and

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Table 1 Characteristics of the OT and FDL-based schemes.

	OT-based scheme	FDL-based scheme
Routing information requirements at source node	Yes	No
FDL requirements at core node	No	Yes
Protection/restoration complexity	High	Low

the just-in-time (JIT) signaling developed under the ATD-Net (formerly MONET) project [3], [5]. In particular, the JET scheme has two features of OT-based scheme and DR scheme.

In this letter, we investigate the problems of the OT/DR-based schemes like the JET protocol and propose a novel FDL/DR with hop-by-hop priority increasing (HPI) scheme in order to enhance the end-to-end efficiency. Through simulation, we compare the performance of the proposed scheme with the existing schemes.

2. Path Length Priority Effect of the OT/DR-Based Scheme

The JET scheme has the features of OT-based scheme and DR scheme. In the OT-based scheme, bursts with a different number of remaining hops to their destinations have different offset times that decrease as the burst traverses each OBS node. In the DR scheme, larger offset times result in lower burst blocking probabilities because a burst with larger offset time can reserve resources in advance [4]. Therefore, when an OT/DR-based scheme like the JET protocol is used, a burst with more remaining hops to its destination will experience a lower burst blocking probability than a burst with fewer hops. This coupling between remaining path length and burst blocking probability results in what is effectively different priority classes for reserving wavelength of a specific link. And, the effective priority of a burst decreases as the burst traverses the OBS nodes. In this letter, we call this problem the *path length priority effect*.

One direct result of this scheme is that the probability, that the bandwidth already used in the upstream nodes will be wasted, also increases as a burst nears its destination. Generally, when considering the overall efficiency of a network, it is desirable that a burst that has already consumed more resources be given priority to complete its transmission over those bursts that have already consumed less. However, the OT/DR-based scheme can cause the opposite effect in reserving wavelength. That is, in the OT/DR-based scheme, the burst blocking probability at each node will increase as the burst traverses the OBS nodes. Therefore, the OT/DR-based scheme degrades the end-to-end efficiency in multiple hop network environments. This unintentional path length priority effect also complicates the use of extra QoS offset time for service differentiation in the OT/DR-based scheme.

3. The Proposed FDL/DR with HPI Scheme

Due to the path length priority effect, the OT/DR-based schemes exhibit higher burst blocking probabilities for a burst that is closer to its destination node. In contrast, the FDL/DR-based scheme can maintain a constant offset between the data burst and its control packet at each node, thereby resulting in no unintentional discrimination in wavelength reservation as a function of the remaining number of hops. Since a burst has generally a long size and a burst

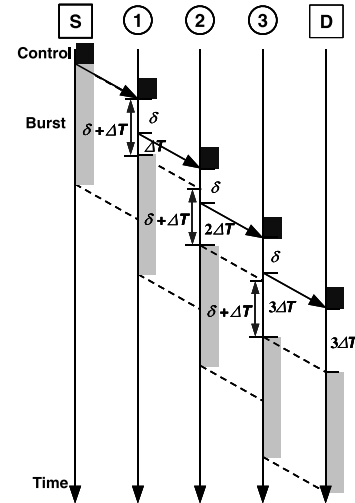


Fig. 1 Basic concept of the proposed FDL/DR with HPI scheme.

blocking wastes the bandwidth of the upstream nodes already consumed on its path, it is desirable that a burst that has traversed more nodes should have higher priority in contending for wavelength than those earlier in their transmission path. Adopting such a policy will enhance overall throughput in multiple hop network environments.

We propose a novel FDL/DR with HPI scheme in order to improve the end-to-end throughput. The basic concept of the FDL/DR with HPI scheme is shown in Fig. 1, where S and D denote the source host (or router) and the destination host (or router) respectively, and δ indicates the processing time of the control packet plus the switch setup time at a core node. The key idea of the FDL/DR with HPI scheme is to increase the priority of a burst hop-by-hop using an extra delay ΔT at each core node. In the proposed scheme, each node uses an input FDL to delay a burst by the amount of the processing time δ plus an extra delay ΔT . Thus, the total offset between the burst and its control packet will increase by ΔT whenever the burst traverses a node. In reserving wavelength, this accumulated offset plays the same role to increase priority as the extra QoS offset time in the JET scheme [4]. Therefore, the proposed scheme guarantees a relatively lower burst blocking probability for bursts that have traversed more hops, resulting in enhancing the total end-to-end throughput in multiple hop network environments. In order to support multiple classes of service, an extra QoS offset time can be assigned at the source node similar to the JET scheme. In this case, ΔT should be determined to avoid any inversion in service differentiation among the classes.

4. Performance Evaluation

In order to investigate the path length priority effect and the end-to-end performance of the wavelength reservation schemes for OBS in multiple hop network environments, we consider a multiple hop network model with ring topology as shown in Fig. 2. In this model, it is assumed that S_1 -

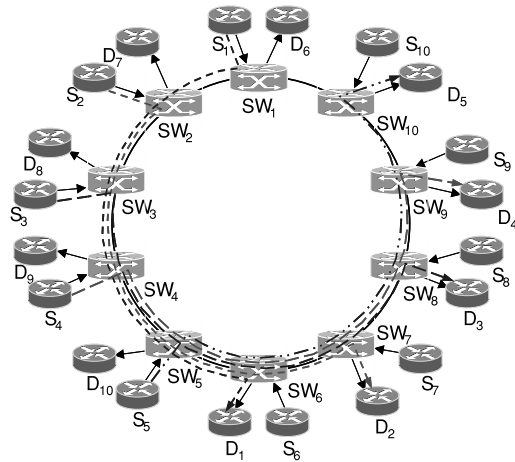


Fig. 2 Network configuration for simulation.

S_{10} are the source nodes and D_1 - D_{10} are their corresponding destination nodes in the OBS networks. The dotted lines indicate the example paths for transmitting the bursts to their destinations. Hence, every burst traverses 5 hops from the source OBS node to the destination OBS node and experience the same offered load intensity at each link. In this configuration, the bursts with different number of remaining hops (from 1 to 5 hops) to their destination OBS nodes contend for reserving wavelength at each link. Also, each link is assumed as consisting of four WDM wavelengths operating at 10 Gbps, and one wavelength is used for the control channel.

The processing time of the control packet plus the switch setup time in each core node is assumed as $\delta = 10 \mu\text{sec}$. And, full wavelength conversions among the data channels are assumed at the OBS nodes. Each source generates the bursts according to an on/off model. The burst length is assumed to be exponentially distributed with an average of 100 kbits. The offered loads of each link are controlled by changing the inter-arrival time of the bursts. We consider $\Delta T = 5 \mu\text{sec}$ for the FDL/DR with HPI scheme.

Figure 3(a) shows the burst blocking probabilities at each hop when the offered load intensities at each OBS node are about 0.8. In this figure, the JET scheme exhibits that the burst blocking probability increases proportionally as the burst traverses each hop due to the path length priority effect. In contrast, the FDL/DR-based scheme shows almost the same burst blocking probabilities at each transit node irrespective of the remaining hops to its destination. Hence, we note that the FDL/DR-based scheme can avoid the path length priority effect. Meanwhile, the FDL/DR with HPI scheme exhibits that the burst blocking probability decreases at each hop as the burst nears its destination. Therefore, this scheme provides that a burst traversed more hops can complete its transmission more successfully.

One peculiar feature of the FDL/DR-based scheme is that the burst blocking probability at the first hop is a little bit higher than those of the other hops. This is due to the fact that the bursts from each source node contend with all the

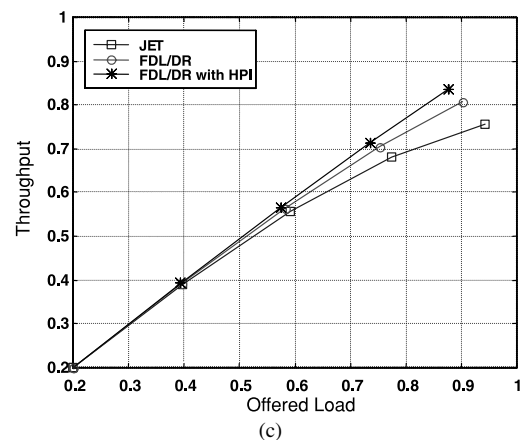
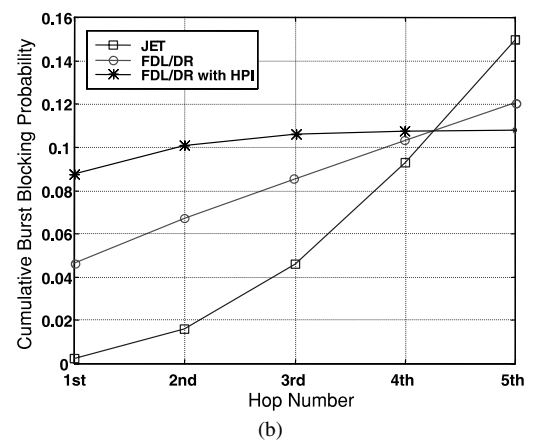
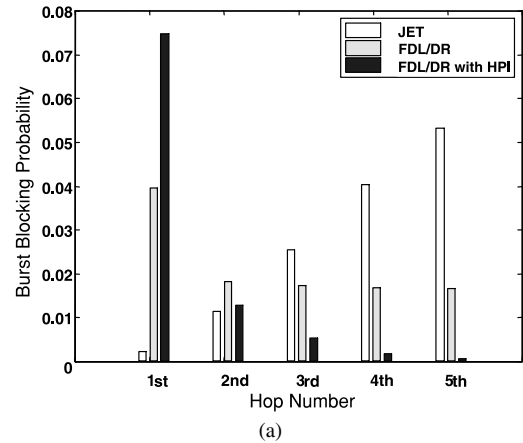


Fig. 3 Comparison of the end-to-end performance. (a) Burst blocking probability at each hop. (b) Cumulative burst blocking probability. (c) Throughput.

other bursts from upstream switching nodes at the first hop, while the bursts from upstream switching node are already aligned in stream at the previous nodes and do not contend each other in this network configuration. In the FDL/DR with HPI scheme, this feature gets intensified because the priority of the bursts at the first hop is relatively lowered by increasing the priority of the bursts which have traversed more hops. Accordingly, this scheme has inherently an ability of burst admission control, because it can control new

bursts to be admitted into the network by blocking them statistically at the first hop when the offered load is excessive.

Figure 3(b) compares the cumulative burst blocking probabilities at each hop for the same traffic load condition as in Fig. 3(a). This figure shows that, compared with the other two schemes, the FDL/DR with HPI scheme exhibits the lowest overall burst blocking probability by increasing the priority of bursts hop-by-hop, even though it has the highest burst blocking probability at the first hop.

From these results of Figs. 3(a) and (b), we therefore expect that the FDL/DR with HPI scheme can improve the end-to-end throughput by reducing the bandwidth waste of dropped bursts.

Figure 3(c) shows the total end-to-end throughput versus the offered load intensity. We depict this figure using the measured offered load intensity since a burst experiences different burst blocking probabilities at each hop according to the reservation schemes as shown in the previous results. The JET scheme exhibits the lowest throughput due to the path length priority effect, while the FDL/DR with HPI scheme gives the best performance in the end-to-end throughput. In this example, when the offered load intensity is about 0.8, the FDL/DR with HPI scheme can improve the throughput by 10% over the JET scheme. And, we note that its improvements in the end-to-end throughput are more remarkable at the higher offered load condition.

5. Conclusion

In this letter, we investigated the path length priority ef-

fect of the OT/DR-based scheme. And, we showed that the FDL-based scheme can avoid the path length priority effect in multiple hop network environments. Also, we proposed a novel FDL/DR with HPI scheme which can improve the end-to-end throughput by increasing the priority of bursts hop-by-hop using the input FDLs at each node. The simulation results showed that the proposed FDL/DR with HPI scheme can avoid the path length priority effect and enhance the end-to-end throughput in multiple hop network environments.

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